REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
30 August 1994

3. REPORT TYPE AND DATES COVERED
Final Technical Report

4. TITLE AND SUBTITLE
A New Approach to Distributed Decision-Making in the Military Command, Control, and Communications (C^3) Systems.

5. FUNDING NUMBERS
Contract
DAAL03-91-G-0158

6. AUTHOR(S)
Sumit Ghosh

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Division of Engineering
Brown University
Providence, RI 02912

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARO 28428.5-MA-SDI

11. SUPPLEMENTARY NOTES
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The proposal's original goal included an investigation of a novel, asynchronous, decentralized approach to military command, control, and communications. Our accomplishments have been substantial and are stated subsequently. We have successfully modeled and simulated complex, broadband-ISDN networks on a network of workstations, configured as a loosely-coupled parallel processor. We have also succeeded in pioneering the concept and design of a dynamic and distributed self-healing algorithm to achieve robustness and high fault tolerance in network management. Our pioneering study of fuzzy thresholding has led to a profound result in network buffer design. Fuzzy queue management adapts superbly to sharp changes in cell arrival rates and maximum burstiness of bursty traffic sources, yielding lower cell discard rates, high throughput of cells through the network, and lower cell-blocking rates. In the world of military command and control that dates back thousands of years, centralized C^3 has been the dominant rule. Except for General Patton in World War II and a few reports in Operations Just Cause and Desert Storm, most military leaders practiced synchronized C^3. Our research is possibly the first to formally characterize and study the concept of decentralized command and control through accurate battlefield simulation on parallel processors, for realistic battlefield scenarios. Performance results indicate that the decentralized C^3 algorithm achieves faster reaction times to new and dynamic information. While this results, for the offensive battlefield scenario, in faster convergence of friendly units on the enemy and resulting higher kills by a factor of 3, for the defensive battlefield scenario, withdrawals occur faster and at a loss of only 17% of strength in contrast to 83% loss for centralized command and control.

14. SUBJECT TERMS
Decentralized Decision-Making, Command & Control, Modeling, Simulation, Warfare

15. NUMBER OF PAGES
9

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

28428-MA-SDI

A New Approach to Distributed Decision-Making in the Military Command, Control, and Communications (C^3) Systems

Final Technical Report

Prof. Sumit Ghosh

August 30, 1994

U.S. Army Research Office

Contract: DAAL03-91-G-0158

Division of Engineering
Brown University

Accesion For		
NTIS CRA&I		X
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Distribution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

Approved for Public Release;
Distribution Unlimited

28428-MA-SDI

A New Approach to Distributed Decision-Making in the Military Command, Control, and Communications (C^3) Systems

Final Technical Report

Prof. Sumit Ghosh

August 30, 1994

U.S. Army Research Office

Contract: DAAL03-91-G-0158

Division of Engineering
Brown University

Approved for Public Release;
Distribution Unlimited

Submitted respectfully
by
Sumit Ghosh
Aug 30, 94

Technical Progress Report (Final)

1. ARO Proposal Number: 28428-MA-SDI
2. Period Covered by Report: July 1, 1991 – June 30, 1994
3. Title of the Proposal: A New Approach to Distributed Decision-Making in Military Command, Control, and Communications (C^3) Systems
4. Contract Number: DAAL03-91-G-0158
5. Name of Institution: Brown University
6. Authors of Report: Sumit Ghosh
7. List of Manuscripts Submitted Under ARO Sponsorship:

- Arthur Chai and Sumit Ghosh, "Modeling and Distributed Simulation of Broadband-ISDNetwork on a Network of Sun Workstations Configured as a Loosely-Coupled Parallel Processor System," IEEE Computer, Vol. 26, No. 9, September 1993, pp. 37-51. *One of two best papers out of approx. 150 papers submitted to the Special Issue on Concurrent Engineering.*
- Tony Lee and Sumit Ghosh, "A Novel Approach to Asynchronous, Decentralized Decision-Making in Military Command and Control," Submitted to IEEE Computational Science and Engineering, August 1994.
- Allen R. Bonde and Sumit Ghosh, "A Comparative Study of Fuzzy Versus "Fixed" Thresholds for Robust Queue Management in Cell-Switching Networks," IEEE/ACM Transactions on Networking, Vol. 2, No. 4, August 1994.

8. Scientific Personnel Supported by this Project:
Principal Investigator (Sumit Ghosh)
Arthur Chai, Sc.B (Honors), May 1992
Tony Lee, M.S., May 1994

9. Report of Inventions: None

Brief Outline of Research Findings

The proposal's original goal included an investigation of a novel, asynchronous, decentralized approach to military command, control, and communications. Our accomplishments have been substantial and are stated subsequently. The communications and military C^3 community and we, the researchers, gratefully acknowledge the support and encouragement of the BMDO/IST (formerly SDIO/IST) office and the US Army Research Office. We have successfully modeled and simulated complex, broadband-ISDN networks on a network of workstations, configured as a loosely-coupled parallel processor. We have also succeeded in pioneering the concept and design of a dynamic and distributed self-healing algorithm to achieve robustness and high fault tolerance in network management. Our pioneering study of fuzzy thresholding has led to a profound result in network buffer design. Fuzzy queue management adapts superbly to sharp changes in cell arrival rates and maximum burstiness of bursty traffic sources, yielding lower cell discard rates, high throughput of cells through the network, and lower cell-blocking rates. In the world of military command and control that dates back thousands of years, centralized C^3 has been the dominant rule. Except for General Patton in World War II and a few reports in Operations Just Cause and Desert Storm, most military leaders practiced synchronized C^3. Our research is possibly the first to formally characterize and study the concept of decentralized command and control through accurate battlefield simulation on parallel processors, for realistic battlefield scenarios. Performance results indicate that the decentralized C^3 algorithm achieves faster reaction times to new and dynamic information. While this results, for the offensive battlefield scenario, in faster convergence of friendly units on the enemy and resulting higher kills by a factor of 3, for the defensive battlefield scenario, withdrawals occur faster and at a loss of only 17% of strength in contrast to 83% loss for centralized command and control.

Through this research opportunity, we believe we have uncovered a basic, fundamental concept in asynchronous algorithm design. The concept can potentially apply to a wide range of important real-world problems. For most real-world problems of interest to researchers and the public, civilian and military data and images are, in general, acquired asynchronously at geographically-dispersed sites, processed, and then propagated to other sites. Synthesized asynchronous, distributed algorithms subject data and images to compression, interpretation, and intelligent processing, locally. Then, an algorithmically-driven scheme automatically propagates the processed information to other physical sites, efficiently and on a need-to-know basis. The scheme exploits local, concurrent, computing power to achieve fast processing, relative to the traditional approach. It offers greater resistance to vulnerability from natural and artificial catastrophies. It greatly reduces the stress on the communications network through

intelligent processing and conversion of voluminous raw data into precise information.

Asynchronous, distributed algorithms, by definition, exploit maximal parallelism, inherent in a problem. Their fundamental philosophy is to intelligently distribute decision-making tasks among the constituent entities to maximize local computations, minimize communications, and achieve robustness and high throughput. Such algorithms are highly efficient and very useful but complex and difficult to synthesize. To the best of our knowledge, the literature reports no studies on synthesizing generic algorithms. For a wide range of problems from the domains of discrete-event simulation, broadband-ISDN networks, military command and control, national payments processing, international payments processing, fault simulation of VLSI CAD, test generation of VLSI CAD, railway networks, and inventory control, the problem is first carefully analyzed and its fundamental components identified. Then, an innovative algorithm is synthesized that satisfies the criteria, noted earlier. Next, the correctness of the algorithms are mathematically proved. These algorithms have been implemented on many parallel processors including the Bell Labs hypercubes, nCUBE, Sequent, Armstrong, and a network of heterogeneous workstations configured as a loosely-coupled parallel processor.

Modeling and Distributed Simulation of a Broadband-ISDN Network on a Network of Workstations Configured as a Loosely-Coupled Parallel Processor

Arthur Chai & Sumit Ghosh
Division of Engineering
Brown University, Providence
Rhode Island 02912

Abstract

Until now, simulations of communication networks have been limited to execution on a uniprocessor computer based on the principles of a centralized discrete-event simulation algorithm. As a result, the modeling of networks has been confined to one, or at best, a limited set of switching nodes. Furthermore, the resulting CPU times for simulations on a uniprocessor have been observed to be overwhelmingly large and, as a result, it has been difficult to model, simulate, and analyze the impact of overload on the performance of the network. This paper proposes a distributed approach to modeling and simulation of complex Broadband Integrated Services Digital Network (B-ISDN) [1] on a network of SUN workstations configured as a loosely-coupled parallel processor. B-ISDN is a high-speed packet switching network wherein computer-, video-, and telephony-data, to be transferred, is divided into small fixed-size elements, referred to as ATM cells, that are routed by "intelligent" switches. B-ISDN is based on the asynchronous transfer mode (ATM) and is planned for use with the synchronous optical network (SONET) [3] as the physical layer. In a loosely-coupled parallel processor system, a number of concurrently executable processors communicate asynchronously via explicit messages over high-speed links. This architecture bears close similarity to the B-ISDN networks and, thus, constitutes a realistic test-bed for the modeling and simulation. Every switching node of the communications network is modeled on a processor of the parallel processor and the traffic flow is represented by the communications protocols. Given that the models of the switching nodes are executed in parallel, the distributed simulation is expected to execute significantly faster than the traditional uniprocessor approach. Furthermore, perhaps for the first time, this approach makes it possible to (i) realistically model overloads in networks, (ii) study their impact on the network performance, and (iii) investigate new schemes to limit overloads from causing uncontrollable performance degradation. This paper describes an implementation of the approach on a network of 50 SUN sparc 1 workstations, configured as a loosely-coupled parallel processor at Brown University. Performance results, based on representative example B-ISDN networks, realistic traffic models, and network characteristics indicate that the distributed approach is significantly efficient and accurate. In addition, this ongoing research facilitates the study of (i) long-term realistic behavior of the network with regard to its throughput and packet loss, (ii) the impact of important network parameters such as buffer size and bandwidth on performance, and (iii) the implications of different network protocols and congestion control scheme proposed by the B-ISDN community.

A Novel Approach to Asynchronous, Decentralized Decision-Making in Military Command and Control

Tony Lee & Sumit Ghosh
Division of Engineering
Brown University, Providence
Rhode Island 02912

Abstract

In a radical shift from the previous doctrine of firepower, attrition, and destruction during the Vietnam era, the current "airland battle" military doctrine is characterized by four key ingredients – depth, initiative, agility, and synchronization. The term, synchronization, implies bringing to bear, at one time and place, the combined power of maneuver, artillery, air, deception, and other systems so as to strike the enemy again and again with an impact that exceeds the sum of all the parts. Throughout military history, in general, synchronization has been achieved through centralized command, control, and communication (C^3), i.e. one where all intelligence is collected and decisions generated at a centralized, sequentially executing entity. Of these four characteristics, however, the synchronization requirement is logically inconsistent with the other three directives, particularly initiative. Evidence from World War II and Operations "Just Cause" and "Desert Storm" indicate that excessive synchronization, realized through centralized C^3, may have caused (i) unnecessary mission failure, (ii) fratricide, and (iii) failure to take advantage of the maximal distributed and concurrent intelligence from the different combat units.

This paper proposes a novel asynchronous, decentralized decision-making algorithm for military command and control. Unlike centralized command and control, in the proposed approach, all entities – infantry, tanks, and aircrafts, of the system are granted significant autonomy, subject to strict guidelines and directives, and provided with the necessary computing power, intelligence gathering facilities, communications gear, and decision-making aids. The overall decision task is distributed among these entities. As a result, every entity's execution is asynchronous, concurrent, and autonomous, leading to efficient and fast decision making. Asynchronous, distributed, discrete-event simulation techniques are utilized to model the problem of military command and control. This ability to model is made possible by the fact that the transfer of discrete data, geographically-dispersed decision-making entities, asynchronously generated stimuli, and the presence of feedback in the data transfer process are the properties of asynchronous, distributed discrete-event simulation algorithm. This paper also presents an implementation of the proposed approach on a testbed of 40+ SUN sparc workstations, configured as a loosely-coupled parallel processor. The goal is to evaluate the performance of the decentralized C^3 algorithm through simulation, under realistic battlefield scenarios, and contrast it with the traditional, centralized C^3. This paper also aims to objectively determine scenarios, if any, where decentralized C^3 is highly effective. A number of experiments are designed to model different engagement scenarios, executed on the simulation testbed, and performance results are reported in the paper. To the best of the authors' knowledge, this research is perhaps the first attempt to scientifically model decentralized C^3 and objectively and accurately assess its performance through extensive parallel simulation. The asynchronism and the resulting complexity of the battlefield and the state of current knowledge limits our ability to develop an accurate analytical model. The simulation testbed represents every entity through an asynchronous, concurrent process. The testbed software is complex, consisting of approximately 20,000 lines of C code and includes a Motif-based graphics user interface. The interface permits the run-time viewing of the simulation either from an

overall view or from the viewpoint of any single entity. It also permits post-mortem replay and analysis. The state-of-the-art battlefield simulators such as SIMNET and CATT provide environments to train personnel in "combined arms" warfare where the decision-making is implemented through the human operators. In contrast, the proposed approach coupled with the parallel simulation testbed offers significant advantage in that it permits a systematic modeling of decision-making in warfare and provides a fast, efficient, and accurate simulation environment. The inputs to the simulation experiments include the starting location of each entity, based on the type of scenario – offensive or defensive, being modeled, and the capabilities of the vehicles and weapons, based on realistic data. Performance results indicate that the decentralized C^3 algorithm achieves faster reaction times to new and dynamic information. While this results, for the offensive battlefield scenario, in faster convergence of friendly units on the enemy and resulting higher kills, for the defensive battlefield scenario, either reinforcements arrive sooner and/or withdrawals occur before heavy casualties are absorbed.

A Comparative Study of Fuzzy Versus "Fixed" Thresholds for Robust Queue Management in Cell-Switching Networks

Allen R. Bonde, Jr.
GTE Government Systems Corporation
Needham Heights, MA 02194
abonde@gte.com
&
Division of Engineering
Brown University, Providence, RI 02912

Sumit Ghosh
Division of Engineering
Brown University, Providence
Rhode Island 02912
sg@lems.brown.edu

Abstract

High performance cell-based communications networks including ATM have been conceived to carry asynchronous traffic sources and support a continuum of transport rates ranging from low bit-rate to high bit-rate traffic. When a number of bursty traffic sources add cells, the network is inevitably subject to congestion. Traditional approaches to congestion management include admission control algorithms, smoothing functions, and the use of finite-sized buffers with queue management techniques. Most queue management schemes, reported in the literature, utilize "fixed" thresholds, i.e. either binary or a limited number of predetermined values based on the cell priorities, to determine when to permit or refuse entry of cells into the buffer. The aim is to achieve a desired tradeoff between the number of cells carried through the network, propagation delays of the cells, and the number of discarded cells. While binary thresholds are excessively restrictive, the rationale underlying the use of a large number of priorities appears to be ad hoc, unnatural, and unclear. This paper introduces, perhaps for the first time, the notion of cell-blocking, wherein a fuzzy thresholding function, based on Zadeh's fuzzy set theory, is utilized to deliberately refuse entry to a fraction of incoming cells from other switches. The blocked cells must be rerouted by the sending switch to other switches and, in the process, they may incur delays. The fraction of blocked cells is a continuous function of the current buffer occupancy level unlike the abrupt, discrete thresholds in the traditional approaches. The fuzzy cell-blocking scheme is simulated on a computer and the simulation results for a given, realistic traffic stimulus, characterized by Poisson arrivals and exponentially distributed departures, are contrasted against those from the traditional approach. A comparative analysis reveals that fuzzy queue management adapts superbly to sharp changes in cell arrival rates and maximum burstiness of bursty traffic sources, yielding lower cell discard rates, high throughput of cells through the network, and lower cell-blocking rates.